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PILOT FACTORS CONSIDERATIONS IN SEE-TO-LAND

THE BUNKER RAMO CORPORATION
ELECTRONIC SYSTEMS DIVISION
WESTLAKE VILLAGE, CALIFORNIA

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The aviation industry is employing a building block approach with respect to aircraft avionics in general and automatic flight control systems in particular, to move systematically from Category I through Category II to Category III operations. The building block approach has been quite effective in structuring what must be done in terms of equipments for delivering the aircraft reliably to the Category I, II and IIIa equipment minima. From an operational viewpoint, however, the recovery of the aircraft still remains a see-to-land operation for these categories. The purpose of this paper is to address the issue of how far

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19. (Cont'd) Visual Guidance; Visual Control; Pilot Factors.

20. (Cont'd) the see-to-land concept can be extended considering the pilot factors constraints in the environment in which the problem exists. The basic question is can the pilot effectively use the equipments in what remains a see-to-land operation?

The low visibility landing experiences of the USAF Flight Dynamics Laboratory and the USAF Instrument Flight Center are heavily drawn upon in the preparation of this report. The results of their flying a Head-Up Display in visibilities down to 400 feet Runway Visual Range (RVR) in a T-39 Sabreliner are reviewed and reported. In addition, a number of other relevant papers and reports are used in helping to describe the nature of the low visibility landing. An assessment is made of some solutions that are being proposed for dealing with the see-to-land problem while considering the pilot factors constraints. stop

The thrust of the paper is directed at two points. First, the decision to go-around or continue the approach below Category I minima is made in a potentially unstable environment that must be considered hostile by any pilot. Secondly, crew procedures, as being practiced, do not add significantly to the safety of the operation. Taking all the factors into account leads to the conclusion that the see-to-land concept is limited, with qualification, to or slightly above Category II limits. The qualification is based on the need to make the pilot's job easier in terms of providing specific guidance on what he must see to continue the approach below Decision Height and how workload could be reduced through realignment of crew duties. Suggestions are made for dealing with both aspects.

Accepting Category II with qualifications as the lower limit of see-to-land directly states that there are only two categories associated with low visibility landing when pilot factors constraints are considered--(1) assured see-to-land and (2) blind landing. It is concluded that efforts in the equipment development area, i.e., Head-Up Display (HUD), and fail-passive autopilots, should be directed toward improving the safety and reliability of the "clear-cut" see-to-land operations rather than being used as "credits" for attaining a Category IIIa capability.

FOREWORD

This report documents the results of the authors' efforts to describe the issues which must be considered when landing operations are conducted on a see-to-land basis, but under very low visibility conditions. The objective of the report is to attempt to establish the lower limit of see-to-land operations when full consideration is given to pilot factors constraints in the low visibility environment.

The work was conducted under Air Force Project 6190, "Control-Display for Air Force aircraft and Aerospace vehicles" which is managed by the Crew Systems Integration Branch, Flight Control Division, Air Force Flight Dynamics Laboratory (AFFDL/FGR), Wright-Patterson AFB, Ohio.

The report was prepared in part by the on site Human Factors Group, located at Wright-Patterson AFB, Ohio, Electronic Systems Division, Bunker Ramo Corporation, Westlake Village, California under USAF Contract No. F33615-73-C-0391.

The authors wish to extend recognition to the many people whose articles, reports and other materials have been drawn upon heavily for this report. Special recognition is given to the contributions made through many years of work on low visibility landing problems by the US Air Force Instrument Flight Center, Randolph AFB, Texas and the Terminal Area Control Branch, AFFDL, Wright-Patterson AFB, Ohio.

The research effort documented herein was performed between April 1974 and January 1975.

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SECTION I

INTRODUCTION

The concept of Category I, Category II, and Category III operations evolved in the late 1950s as a means for the commercial aviation community to systematically undertake the achievement of a low approach and landing capability down to and including zero-zero. In the middle 1960s, Category III was sub-divided into Category IIIa, IIIb and IIIc to further delineate levels of capability. The category definitions have generally been accepted on an international basis (ICAO-PANS/OPS, Annex 10).

Category I procedures provide for approaches to a decision height (DH) of not less than 200 feet and visibility of not less than 2400 Runway Visual Range (RVR)* (1800 RVR with operative touchdown zone and centerline lights). Category II procedures allow for approaches to minima as low as DH 100 feet/RVR 1200 (Ref. 1). The assumption that is implicit in these definitions is that the pilot has sufficient time and visual cues for completing the landing successfully and reliably in each case.

The FAA approved Category II operation for the airlines over six years ago. There is a concensus that Category II is safe with the training, auto-pilots, flight directors, and ground aids available to the air carrier pilot/crew. There is some question as to how often the privilege has been exercised. However, there has been no known accident directly attributable to hazards imposed by landing in a Category II environment.

Category IIIa operations also are reliant to a degree upon visual references. For example, Category IIIa is defined as "operations with no DH limitation, to and along the runway with external visual reference during the final phase of the landing and with RVR not less than a value on the order of 700 feet..." Pilot intervention other than decrab and power adjustments shall not normally be required." Cat IIIa pilot training will include "the visual approach aids; i.e., approach lights...Procedures for transitioning from non-visual to visual flight and procedures to be used in deteriorating visibility conditions" (Ref. 2). (Underlining by author for emphasis.)

The dependence upon see-to-land in a Category IIIa environment may well be questionable until more data are in. The Lockheed 1011 and DC-10 aircraft were certified for Category IIIa. The certification deals

*Runway Visual Range is defined as the horizontal distance a pilot will see down the runway from the approach end, based on the sighting of high intensity runway lights or other targets. It is determined by a computation of the transmission reading, the runway light intensity setting, and the background illumination reading.

with the equipment side of the problem. That is, the landing systems have been certified as meeting criteria for delivering the aircraft to the alert height* accurately and reliably (Ref. 2). What has not been addressed in any depth is the adequacy of the visual environment for supporting a see-to-land concept.

The USAF Instrument Flight Center (IFC), in conjunction with the USAF Flight Dynamics Laboratory (AFFDL) conducted a systematic evaluation of the environmental and psychological aspects associated with low visibility approach and landing down to and including Category IIIb (150' RVR). A T-39 aircraft, the Sabreliner, was used in the program which was conducted between 1964 and 1968. The results were reported to the aviation community in 1972 (Ref. 3). This work was extended in 1972 to include the use of a head-up display in low visibility approaches down to 400 RVR. Overall, approximately 270 approaches were made in the program. The pilot data produced by these efforts form the basis for observations on the feasibility of see-to-land below Category II minima in this paper.

The purpose of this paper is to address the issue of how far the see-to-land concept can be extended in accomplishing approach and landing under low visibility conditions. As will be shown in the paper, Category II and III are fog based conditions, while Category I more often than not is cloud based. The instability of the fog coupled with other associated factors -- crew duty, how visual cues are acquired, limitations of visibility measuring devices, the severely limited time to make decisions, and proximity to the ground -- all contribute to a legitimate concern over the feasibility of see-to-land in less than Category II.

The experience obtained by the IFC and the AFFDL in flying a HUD in less than Category II shows why the device, contrary to the thinking in some quarters, is not the cure-all solution. There are problems regarding the utility of the HUD which require a conservative approach until more data are in. No solutions are provided in the paper. The paper is intended to focus on the most difficult aspects of the landing problem experienced by the pilot and is meant to stimulate thought, discussion, and concern for that part of the landing maneuver for which the issues are just beginning to crystalize. As will be shown, the problem confronting the pilot is complex and a number of interrelated issues bear upon how well the maneuver can be accomplished in less than Category II.

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*Alert Height - a height (100' or less above the TDZ), established, based on the characteristics of the aircraft and the particular airborne Cat IIIa system, above which a Cat IIIa approach would be discontinued and a missed approach executed if a failure occurred in one of the required redundant operational systems in the aircraft or in the ground equipment.

The consequences of determining how far the see-to-land concept can be extended both with and without a HUD have far reaching consequences from an economic, as well as a flight safety point of view. Equipment requirements (autopilots, instruments, etc.) are directly based upon delivering the aircraft to a position from which the pilot takes over and lands visually. If see-to-land is not feasible when the constraints of the environment and pilot/crew are imposed in less than Category II weather, then the operator must be prepared to operate that aircraft just to Category II or all the way to the runway, automatically.

There is a considerable difference in the sophistication of the autoland system needed for Cat II and Cat III conditions, respectfully. These differences are directly correlated with costs. The whole idea of what equipment to install for any particular aircraft may get much simpler, and in the case of assured see-to-land, much cheaper when the pilot and crew constraints are considered.

SECTION II

THE SEE-TO-LAND CONCEPT

The "see-to-land" concept has never been unequivocally defined, but has come to mean different things to different people at different times. In an attempt to clarify "see-to-land" (at least for the purposes of this paper), the following criteria are stated:

> The pilot must have sufficient visual reference to land his aircraft as in contact flying. The visual reference must allow him to control the aircraft in roll, yaw and runway alignment. They must allow visual control of aircraft pitch and alignment without assistance from instruments* or autopilot. "If the pilot is required to rely on ballistics or aircraft systems for control or alignment, his visual reference is obviously inadequate for a see-to-land operation." (Ref. 4)

A. Decision Height and the Decision Process

Any discussion of the see-to-land process would be incomplete without touching upon one of the important fundamentals of the concept - decision height.

1. Definition of Decision Height. There has, in the past, been considerable controversy over the definitions of DH. The USAF definition as contained in Air Force Manual (AFM) 51-37 states "DH is the lowest altitude at which a missed approach will be initiated if sufficient visual reference with the runway environment has not been established." The definition as contained in FAA Handbook 8260.3A, U.S. Standard for Terminal Procedures (TERPS) (Ref. 5) is as follows:

> "Decision Height (DH). The height, specified in MSL (Mean Sea Level), above the highest runway elevation in the touchdown zone at which a missed approach shall be initiated if the required visual reference has not been established."

Since this definition was interpreted in varying ways, a clarifying statement was made by Mr. Joseph A. Ferrarese, Chief of FAA's Operations Division, in a paper presented at the SAE National Aeronautics Meeting and Production Forum, 25-29 April 1966 (Ref. 6). Mr. Ferrarese stated:

> "The term 'decision height' has two distinct meanings, although not completely identical to those of meteorological ceiling. First, it is a specified height above the landing surface providing an established uniform baseline,

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*Airspeed excepted since this parameter cannot be controlled visually in high performance aircraft.

and secondly, it has operational meaning, which must be defined in terms of pilot assessment factors which come into play in the decision-making process. With regard to the determination of decision height, the value is defined as the distance between the wheels of the aircraft, with the aircraft on the glide slope, and the highest runway elevation in the touchdown zone. From an operational standpoint, decision height is the limit to which a pilot may descend before deciding to continue his approach to a landing by means of visual aids and cues, or to execute a missed approach. This is not to say that the pilot waits until he arrives at the decision height before deciding whether to land or go around. The decision-making process begins at the time the ILS approach is initiated and continues while the approach is in progress....

It, therefore, becomes evident that while the decision height is an exact point in space at which the pilot makes an operational decision, the information he requires to make this decision has been accumulating for a considerable time, and it would be incorrect to assume that all aspects of this decision must be formulated and assessed at one critical instant on the approach."

2. Required Visual Reference at DH. The foregoing defines the DH from the regulatory point of view. The one element that has not been pinned down is "the required visual reference." At least two distinct positions have evolved as the low visibility environment is assaulted: (1) Federal Aviation Regulation, Part 91 (Ref. 7), defines the required visual reference as the ability to see certain items identifiable with the approach end of the runway. Specifically, "the approach threshold of the runway, or approach lights or other markings identifiable with the approach end of that runway." This seems clear enough that something should be seen, but does not indicate how much of it needs to be seen. Mr. Ferrarese's position on this from his April 1966 paper (Ref. 6) was:

"Neither should we try to tell the pilot that he must see a particular visual segment before continuing his approach to landing. This is completely a matter of pilot judgment, and since many variables are involved, it would be unwise to attempt to be specific and to legislate a requirement for a particular visual segment."

(2) The other fairly distinct position on the "required visual reference" is: If the pilot's aiming point is obscured, the visual information is inadequate for control of the vertical situation. This position is supported by a good many pilot and research groups, and has as one of its staunchest supporters, Capt. Larry DeCelles, of the ALPA All Weather Flying Committee. Capt. DeCelles has this to say in his 17th Air Safety Forum paper, "The Fail Safe Landing." (Ref. 4)

> "We remain convinced that the minimum visual reference adequate for control of pitch and glidepath during descent below a critical height must include the runway aiming point." He states further, "We propose that the required visual reference for continuing descent below decision height be specified as the ability to see at least the threshold of the runway."

3. The Decision Process. The definition of DH seems clear enough and the justification is strong for requiring some well defined point in sight as a prerequisite for continuing past DH. However, under present procedures, the decision maker may be faced with a dilemma in that at 100' DH on a 2.5 degree glideslope, the pilot is approximately 1400' from the threshold. Mr. Ferrarese said in his reply to Capt DeCelles "Fail-Safe Landing" paper (Ref. 8):

> "Seeing the runway threshold as a condition for descending below the DH certainly does not give us any problem. However, because of the geometry of certain ILS installations, the threshold may not be visible in a homogeneous weather condition."

The discussion leads to the conclusion that the DH and RVR relationship may not be a valid one from the pilot's position for some ILS approaches. Attempts to determine the logic behind this relationship essentially lead to the conclusion that Category II minimums (100 ft. DH-1200 RVR) were arrived at by mathematically halving Category I minimums (200 DH - 2400 RVR). This is substantiated by FAA's reply (Ref. 4) to an ALPA query on the matter.

> "There were no studies made on the location of the Cat II decision height. However, NAFEC obstacle clearance studies supported this decision and the criteria is incorporated in Advisory Circular 120-20. Actually it was based on the logical conclusion that since the Category II RVR is one-half of the Category I RVR, the decision height should be 100 feet."

Unfortunately, this logic did not recognize the fact that in progressing from Category I to Category II and below, the nature of the weather changes

from one of essentially cloud based restrictions with relatively good visibility after "break-out" in Cat I to a more homogeneous restriction to visibility in Cat II that does not necessarily conform to mathematical ratios with Category I conditions. This situation requires a thorough discussion of the nature of the low visibility environment.

SECTION III

THE NATURE OF THE LOW VISIBILITY LANDING

There are many phenomenon such as rain, haze, and fog which restrict visibility. Visibility (or visual range) is generally defined as the greatest distance that prominent objects can be seen and identified by unaided, normal eyes through the restriction to visibility. During a landing approach, pilots are concerned with the following types of visibilities: (1) prevailing visibility at the airport, (2) slant visual range (pilot's maximum visibility over the aircraft nose toward a ground based object), and (3) runway visual range (RVR).

Prevailing visibility and RVR information are generally readily available to the pilot. However, no practical method has yet been put into use for measurement of slant visual range (SVR). SVR becomes of vital importance to the pilot when attempting to land under low visibility conditions. And, unfortunately, prevailing visibility, RVR, and SVR may all be quite different.

A. Restrictions to Visibility

The type and intensity of restrictions to visibility depend largely on the stability of the associated air mass. Stable air is favorable for the formation of fog, low clouds and light precipitation which restrict visibility. Likewise, haze and smoke are trapped in stable layers of the atmosphere. On the other hand, unstable air produces vertical currents which tend to lift and dissipate fog, as well as lift and spread haze and smoke. Blowing dust, blowing snow, and heavy rain showers, which also reduce visibility, are associated primarily with unstable air masses.

1. Fog. Of all visibility restrictions, fog is the most common restriction below Cat I and presents the most common hazard to safe, visual landings. Fog generally reduces visibility to values of less than three miles and on occasions to zero. Horizontal flight visibility is generally good above fog, while slant range visibility is generally poor in fog.

Fog is a suspension of minute water droplets in the atmosphere. It is usually gray, and of course, "feels" damp. The small droplet size of the water content of fog effectively reduces the transmissivity of light in the atmosphere. The functional relationship of the water content to transmissivity is well known (Ref. 9) and is graphically illustrated in Figure 1. As shown, large droplets (precipitation) do not restrict visibility to the same extent as small droplets (fog). There is similarity between low clouds and fog. The distinction between the two (Ref. 10) is that the base of fog is from the earth's surface, upward through 50 feet, and the base of clouds must be at least 51 feet above the ground. The significance of this distinction lies in what the pilot may expect in terms of visual segment and the manner in which it develops during the approach.

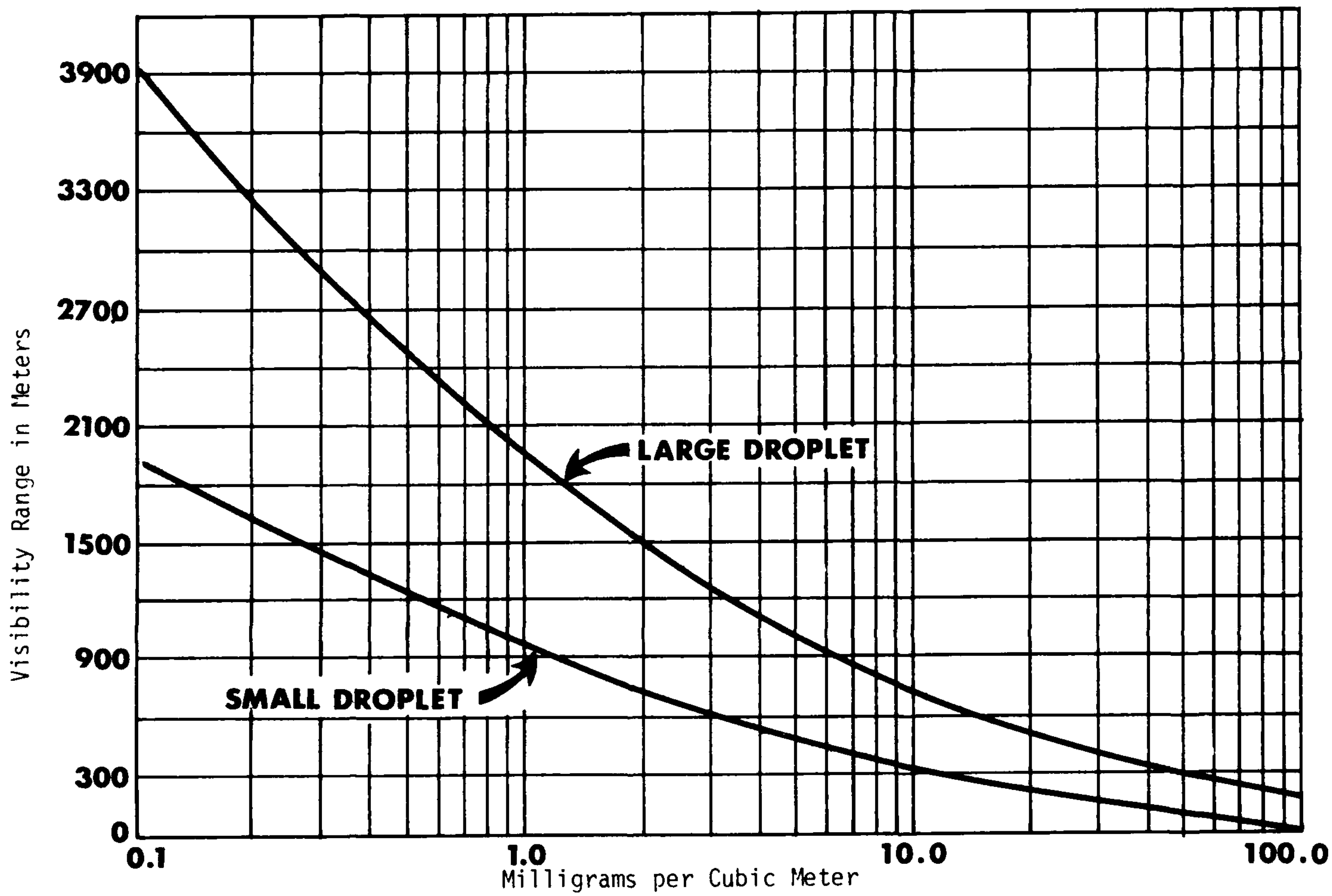


Figure 1. **VISIBILITY RANGE DAYLIGHT FOG VERSUS WATER CONTENT**

From an operational standpoint hazardous visibility conditions fall into three broad categories - two types of fog and a cloud base condition. The two types of fog are radiation and advection.

2. Radiation or Shallow Fog. This type fog, sometimes called ground fog, forms on clear, nearly calm nights when the ground loses heat very rapidly. The air in contact with the ground is cooled by conduction, the relative humidity increases, and condensation occurs. If a complete calm exists, usually only very shallow layers of fog will form.

Light wind of 5 knots or so produces a mixing action which spreads the cooling through a deeper layer and may result in the top of the layer reaching as high as 200 feet.

On occasion, it may mature and become so deep that its characteristics become similar to that of advection fog. Generally speaking, however, radiation fog seldom exceeds a height of 200 feet and is usually associated with partially obscured conditions.

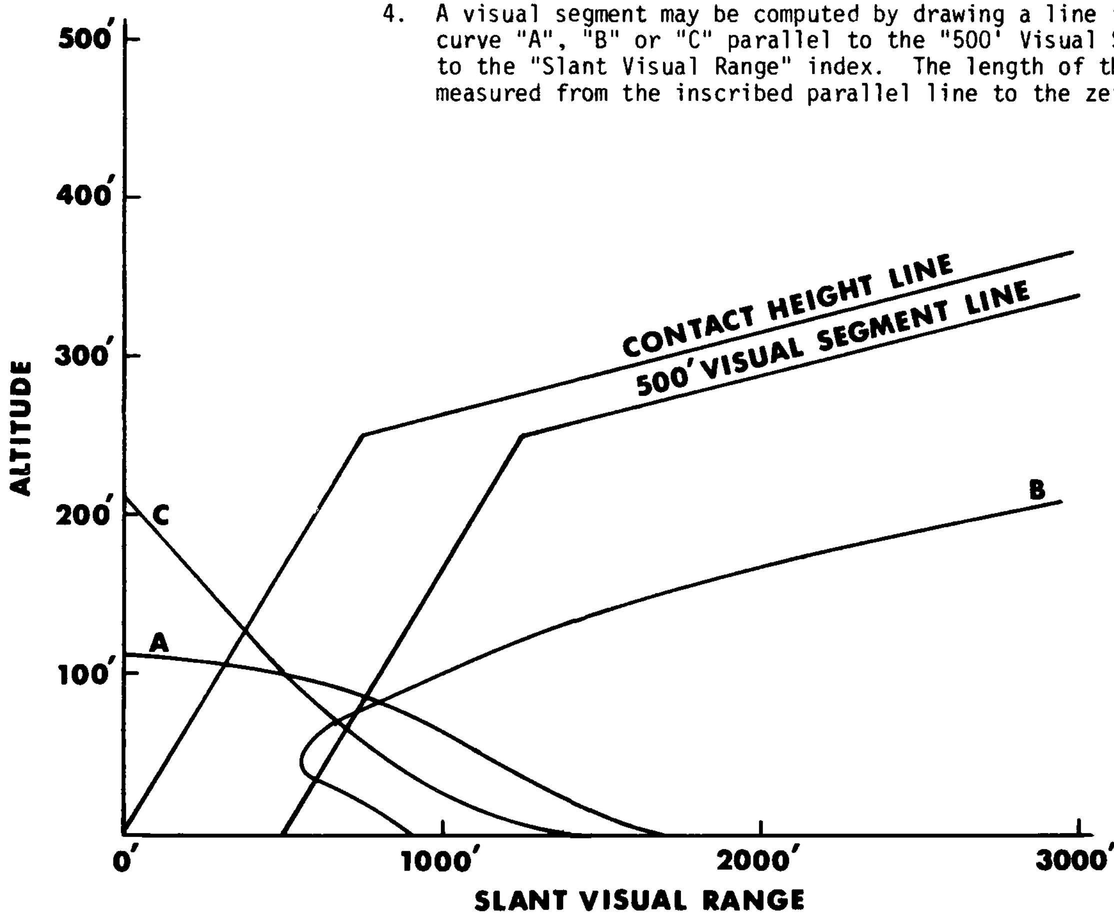
NOTE: Since this fog is frequently patchy, it is probable that the pilot's visibility will vary greatly during approach and landing. This patchy condition may also result in wide variances between reported RVR and conditions actually encountered by the pilot. This fact, coupled with the relative abundance of visual cues early in the approach can frequently entice the unwary pilot to continue into an extremely hazardous situation.

Reference to Figure 2, Curve B, shows that visual contact may be established early in the approach. As the aircraft descends, the visibility decreases to a minimum just below the top of the fog and then depending upon the fog thickness, the visibility may or may not increase again nearing touchdown. As the fog layer is entered, most or all of the visual cues may be lost.

If the pilot is not flying on instruments at this point, he may become disoriented. Indeed, if the pilot is not fully prepared, this visual segment may cause him to think that the aircraft has pitched up. His reaction might be to push the nose of the aircraft down, which would cause the visual segment to appear normal again and bring his projected impact point into the visual segment. Unless the situation is recognized quickly, high rates of descent and disaster may result. The situation described here may well be why aircraft periodically unintentionally depart or "duck-under" the glideslope and impact short of the runway under marginal weather conditions.

As an alternative to an early decision to land and subsequent loss of visual cues, the pilot may, when confronted with this situation, elect to attempt a missed approach either on instruments or visually. At any

NOTE:
1. Over the nose ground visibility is zero above the "Contact Height Line."
2. Over the nose ground visual contact occurs when curve "A" or "C" intersects "Contact Height Line." Curve "B" is always in visual ground contact.
3. SVR is indicated vertically from any point on curve "A", "B" or "C".
4. A visual segment may be computed by drawing a line from any point along curve "A", "B" or "C" parallel to the "500' Visual Segment Line" down to the "Slant Visual Range" index. The length of the visual segment is measured from the inscribed parallel line to the zero index.



A Cloud Base Conditions
B Shallow Fog Conditions
C Mature Fog Conditions

Figure 2. Typical Curves for Three Fog Conditions

rate, he is faced with an instantaneous decision between two actions, either of which may be considered dangerous considering the proximity of the ground.

3. Advection or Deep Fog. Advection fog or deep fog is very common along coastal regions and at sea. It is produced by cooling of the lower layers of warm, moist air as it moves over a colder surface. Wind speeds of up to 15 knots deepens the fog to a height of several hundred feet. A stronger wind and resulting turbulence usually lifts the fog, and stratus clouds form.

Deep fog is usually associated with obscured conditions. Reference to Figure 2, Curve C, shows that in deep fog, the visual segment usually increases as altitude is lost during the approach. However, it must be noted that deep fogs nearly always cause Category III conditions and the visual segment will generally be small. In Figure 2, a sample 500' visual segment is illustrated by the fog curves (A, B and C) intercepting the 500' Visual Segment Line.

As visual contact develops, deep, homogeneous* fog presents the same sorts of illusions to the pilot as shallow fog, but it is not as treacherous. As the pilot starts to observe visual cues, the projected impact point of the aircraft will very likely be well beyond the leading edge of the visual segment (point where contrast ratios fall below visual threshold values and the fog appears opaque). This situation gives the pilot the feeling of being too high and going higher. Unless resisted, this also may result in a push over to achieve an increase in the visual segment and bring the projected impact point into view. The redeeming factor here is that the situation develops more slowly than in shallow fog and the visual segment nearly always increases as altitude is lost.

Advection fog that is undergoing lifting actions from winds stronger than about 15 knots (sometimes referred to as non-homogeneous fog) may present piloting problems similar to that of the shallow fog. Visibility may fluctuate rapidly since the lifting action causes what might be considered as a combination of deep, ground based fog and a cloud base condition. In addition to the problems of a rapidly fluctuating visual segment, the turbulence will make instrument flight more demanding and the winds may generate the requirement for a decrab.

4. Cloud Base Condition. Poor approach conditions may occur as a result of low ceilings. Low ceilings frequently consist of stratus type clouds which are often formed by the dissipation or lifting of the lower layers of a fog bank (remember...in this paper, fog with a base in excess of 50 feet becomes a cloud.)

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*Homogeneous as used here refers to horizontal visibility only. Characteristics of fog in the vertical axis are not well defined.

In reference to Figure 2, Curve A indicates that after visual contact, the SVR in cloud base conditions increases rapidly and continuously until touchdown. Therefore, the majority of approaches in cloud base conditions are flown with higher than Category II minimums. Landings from approaches made in cloud base conditions generally present no particular problem for the pilot since typically a "break-out" occurs with the projected touchdown point in view at or before decision height. A cloud base condition can be hazardous, however. In the case where lifting causes a deep mature fog to become a cloud base condition, patches of fog may still exist between the cloud base and the ground. This situation presents problems very similar to the rapidly fluctuating visual segments discussed previously.

B. Reported Visibility and Its' Problems

It can be deduced from the preceding discussion that visibility becomes of extreme importance to the pilot in a "see-to-land" situation. However, the pilot arrives today in the decision area of the approach without knowing exactly what visibility conditions exist, much less any firm guidance on what he should see specifically.

1. Runway Visual Range. The pilot will be provided with RVR if it is a criteria for the approach. The value is obtained automatically from a transmissometer which may be located up to one half mile from the decision area and considerably below the pilot's eye level. This value may be in error by several hundred feet because of patchy conditions since fog is rarely uniform. Fog can move in patches along and across the runway resulting in visual ranges changing by 100% in as little as 10 seconds. The pilot approaching at 120 to 150 knots and descending at 10-15 feet per second could experience radical fluctuations in visual range at a far greater rate if exposed to this type of situation.

Present day RVR systems, at best, provide an approximation of actual visual range conditions the pilot will encounter.

2. Slant Visual Range. SVR is generally referred to as the maximum distance that a pilot can see along the approach path toward touchdown. For a given visibility condition, this extends from the pilot's eye position to the point where contrast ratios fall below threshold values of the eye and the fog appears opaque. SVR is the important visibility value to the pilot since he uses this for visual positioning and guidance of his aircraft. While research efforts are underway, no practical method has yet been put into practice for measurement of SVR. The pilot's own observation taken during the approach remains the most meaningful one.

3. SVR vs. RVR. The disparities between SVR and RVR further compound the pilot's problems. Two points were brought out by USAF pilots during the Landing Weather Minimums Investigation (Ref. 3). These points are:

(a) RVR-SVR differences as great as 2000 feet occur during Category II and III conditions.

(b) Due to siting requirements and sampling limitations, the sensors seldom reflect the visibility encountered by the pilot during Category II and III approaches.

Even though the relationship of SVR to RVR is much too complex to define specifically, measurements taken by the British at two representative airports indicate that with a desired visual contact probability of 80-90%, SVR:RVR ratio is in the general range of 0.65 to 0.85. Similar findings were also reported by project pilots of the AF Landing Weather Minimums investigation.

In summary, even though RVR represents great advancement over previous methods of reporting, it still falls far short of indicating to the pilot exactly what visibility to expect during a particular approach. A method needs to be developed that will "assure" the pilot that he does (or does not) have the required landing visibility as he approaches decision height.

C. How Visual Cues Occur

The see-to-land process is essentially one of maintaining a closed instrument loop or instrument scan until approaching DH, whereupon the pilot begins to scan for outside visual references while maintaining aircraft control with instrument guidance. As visual cues develop at or before DH, the pilot uses both instrument and visual cues for aircraft control. When the pilot feels comfortable with the available visual cues, before or at DH, he transitions to a closed visual loop, using only the visual scene for guidance to complete the approach and landing. The variables that effect the foregoing see-to-land process are numerous. For example, crew size, crew procedures, day/night and airport familiarity may effect how early the pilot will start looking for visual cues. Turbulence, experience, geographic considerations, and how well the visual cues relate to instrument guidance may effect how long the pilot uses both instrument and visual guidance. In very low visibility, this composite guidance situation frequently extends to touchdown. (Ref. AFM 51-37, Pg. 17-13) However, as stated earlier (page 4) in this paper, the "see-to-land" process does not involve instrument guidance beyond DH.

The visual cues during low visibility conditions appear to the pilot gradually and in fragments. That is, the runway environment does not suddenly appear as in the traditional "break-out" from a cloud base condition. Furthermore, if the restriction to visibility is a homogeneous fog condition, information that can be extracted from visual cues appear in a repeatable fashion.

1. <u>Lateral Axis</u>. First, visual contact will be established with a single object or light. Identification of this object or light may allow establishment of lateral position. As additional cues come into view, lateral position may definitely be established followed shortly by the ability to visually control the aircraft in the lateral axis. Opinions vary widely on the visual segment required to fully control the

lateral axis. However, the AF Landing Weather Minimums Investigation (LWMI) concluded that 1200 feet RVR which yielded a pilot visual segment of 600 - 800 feet provided for marginal visual control of the test aircraft (Sabreliner). It was found, however, that the head-up pilot could assist the head-down pilot in a limited way through full time "force wheel steering" (Ref. 3), with visual segments down to 200 feet (in very light cross wind conditions). It was further concluded that visual contact with a single row of lights within the visual segment might be sufficient for lateral control. At any rate, it appears conclusive that lateral position and lateral axis control is easier to achieve or can be achieved with fewer visual cues than is required for visual control of the vertical situation.

2. Vertical Axis. It was determined during the LWMI Study and is commonly accepted that more visual cues or a greater visual segment is required for control of the vertical axis than is required for the lateral axis. During the LWMI, lateral control could be assumed by the head-up pilot about 4-6 seconds before he was willing to assume vertical control. Sixteen hundred feet RVR was considered to be the lowest practical visual range to attempt visual landings. Because of cockpit cutoff angle, relationship of RVR to SVR, etc., 1600 feet RVR yielded a visual segment of approximately 1200 feet at 100 feet above the surface. This would indicate a visual segment requirement two times greater than the visual distance required by the generally accepted premise that the forward visible ground segment must be equal to the distance traveled in 3 seconds, at a ground speed of approximately 200 feet per second. It is believed by many that reliable visual vertical control of an aircraft begins only when the pilot can see discreet and identifiable points such as the runway threshold and does not fully develop until he can see the projected touchdown point or "aimpoint."

Mr. O. B. St. John, Superintendent of the Blind Landing Experimental Unit (BLEU), Royal Aircraft Establishment, in his report "All Weather Landing" had this to say about visual control of the vertical flight path during landing (Ref. 11):

> "In clear visibility the pilot controls his flight path by an appreciation of the relative position of the horizon and the point at which he is aiming to land. If his horizon becomes obscured, his assessment of his flight path angle is impaired and he attempts to compare his aiming point with the point toward which he thinks the aircraft is flying. If his aiming point is also obscured, the visual information is clearly inadequate for real safety."

Mr. Calvert of the Royal Aircraft Establishment also made extensive studies into the problem of visual pitch control in low visibilities. His argument can be summarized as follows (Ref. 12):

"In making his decision whether to continue with the landing or not after becoming visual, the pilot must assess not only his position relative to the ideal flight path, but also his velocities, both cross track and vertical, to determine where the aircraft is going. Whilst it is reasonable to expect a proficient pilot to be able to assess the aircraft's position and velocity in the horizontal plane by looking at a segment of approach lighting which includes only one cross bar, it is more difficult, if not impossible, to make a similar assessment in the pitch plane from the same picture. Even gross errors may be difficult to detect in the time available after visual contact in operations to the lower decision heights of Category II. It is believed that visual control of the aeroplane in pitch begins to become reliable when the pilot can see as far as the point on the ground to which his approach path is heading. For a glideslope angle of 3 degrees and a slant range of 400 metres, this occurs when the pilot's eye height is as low as 70 feet, and even for a slant range of 800 metres, the eye height is 140 feet. This means, to achieve high standards of safety in these visual conditions, instrument guidance in pitch is required to heights of around 50 to 100 feet."

D. Time Exposure to Visual Cues

To this point the amount and sequence of emerging cues within the visual segment have been discussed. But another factor must be considered in determining the adequacy and suitability of visual cues - the time which the visual cues are observed by the pilot.

In addition to observing "sufficient" visual cues, the pilot must observe them long enough to make use of them. Displacement from the desired position can be determined more easily than velocities. Trends and cross track rates can only be determined after a period of observation. In any case, as the visual cues are observed, a great deal of information must be extracted, absorbed and reacted to, such as:

Displacement in both lateral and vertical axis; crab angle; roll and pitch attitudes; roll and pitch rates; vertical and lateral rates; an estimate of time to go; adequacy of visual cues for continuing the approach; and a myriad of these sorts of things that make up a visual landing.

At some point during the approach, the pilot must decide to transfer guidance from the instrument loop to the visual loop and initiate corrections based on the obscurred visual segment. Such corrections require time: time to integrate the visual cues into a visual scene; and time to maneuver. Continuous feedback from the visual scene after the transition to visual guidance is critical to the success of the time oriented see-to-land process.

The LWMI Study concluded the following:

"To use a limited visual segment for establishing visual flight requires interpretation time. When cues are first seen, aircraft position may be known, but what is not known is exactly what the aircraft is doing with relation to the cues perceived. The time required to integrate and determine movement depends to some extent on the length of the visual segment and the cues within a visual segment. Visual segments of 1200 feet generally presented project pilots with little difficulty determining lateral and vertical movement. However, as segments decreased toward 600 feet, visual perception of movement becomes extremely difficult and pilots required 3 to 4 seconds to effectively interpret visual cues. One explanation of this observation would be that as the visual segment decreases, it does not present enough information to rapidly determine cross track rate. It would seem logical to assume that the shorter the visual segment became, the longer the time required to perceive movement."

E. Cockpit Cut-off Angle

The "see-to-land" concept is obviously limited to some finite values of RVR/SVR. However, there is an additional restriction which must be considered - the geometry of the pilots viewing angle as affected by the cockpit cut-off angle. This geometry, combined with SVR yields the pilot's visual segment (fig.3). At a given instant and SVR condition, the visual segment is bounded by the limits of the pilot's forward visibility (point where contrast ratios fall below threshold values and the fog appears opaque or the fog line) and the cockpit cutoff angle (fig.4). Since the trailing edge of the visual segment is controlled by the cockpit cut-off angle, it can be seen that aircraft attitude changes for whatever reason directly affects the length of the pilot's visual segment, thereby having direct impact on the utility of the visual segment.

F. Approach Profile Geometry

Instrument approach geometry becomes a consideration during see-to-land operations. The geometry of an approach flown visually differs significantly in the vertical plane from that flown on instruments. Work performed by Litchford (Ref. 13) and the AFFDL (Ref. 14) show that the visual approach is flown at a steeper angle, usually close to 4 degrees, with the GPIP located either at the threshold or just short of threshold. At an altitude of approximately 75 feet, the pilot transitions to a shallower angle, i.e., 2.5 degrees, crosses the threshold at approximately 15 feet and lands in the first 1000 feet of the runway.

In contrast, the instrument approach is flown at a constant 2.5 to 3.0 degrees with a GPIP approximately 1000 feet down the runway. Con-

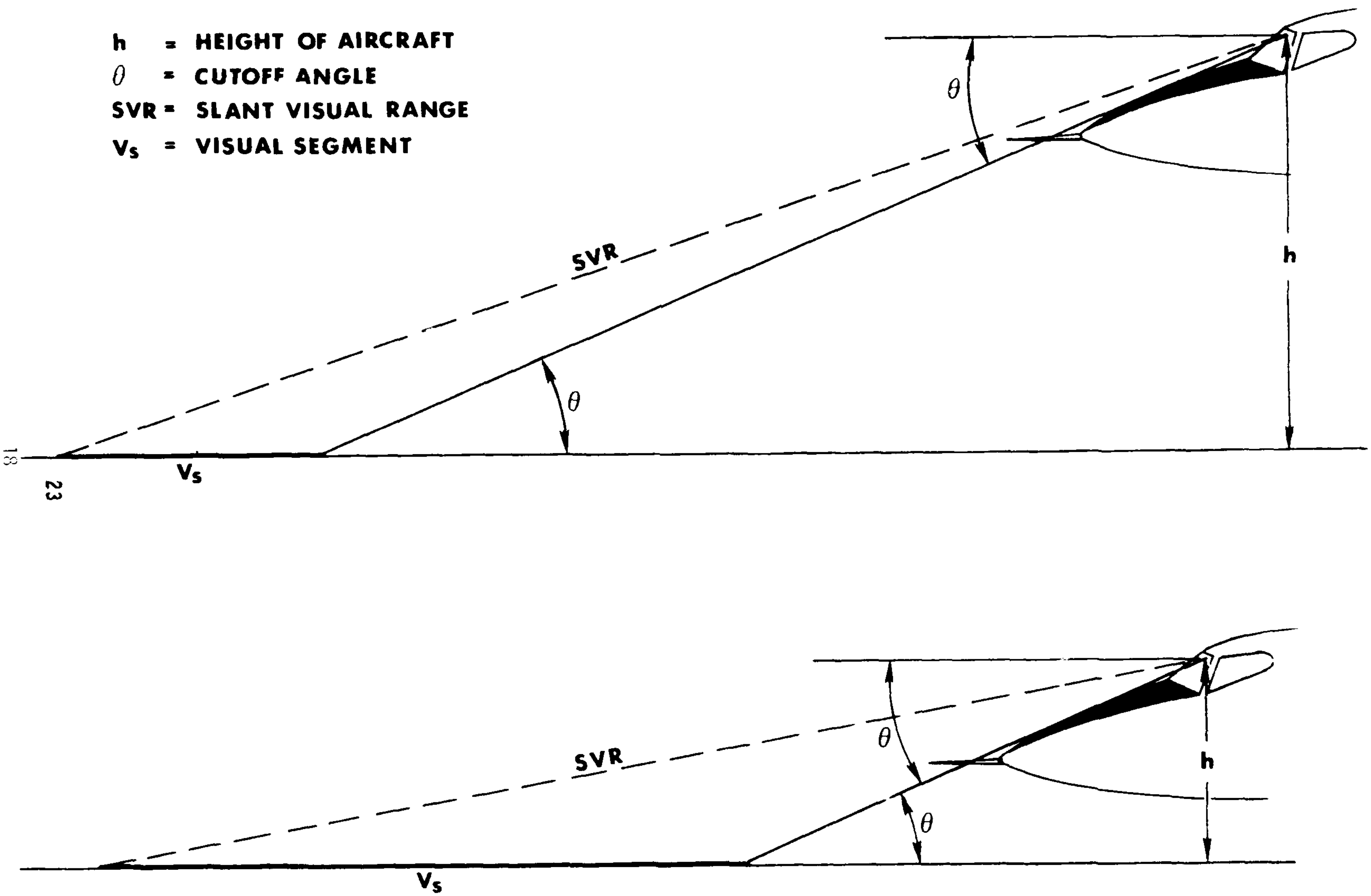

Figure 3. **EFFECTS OF COCKPIT CUTOFF**

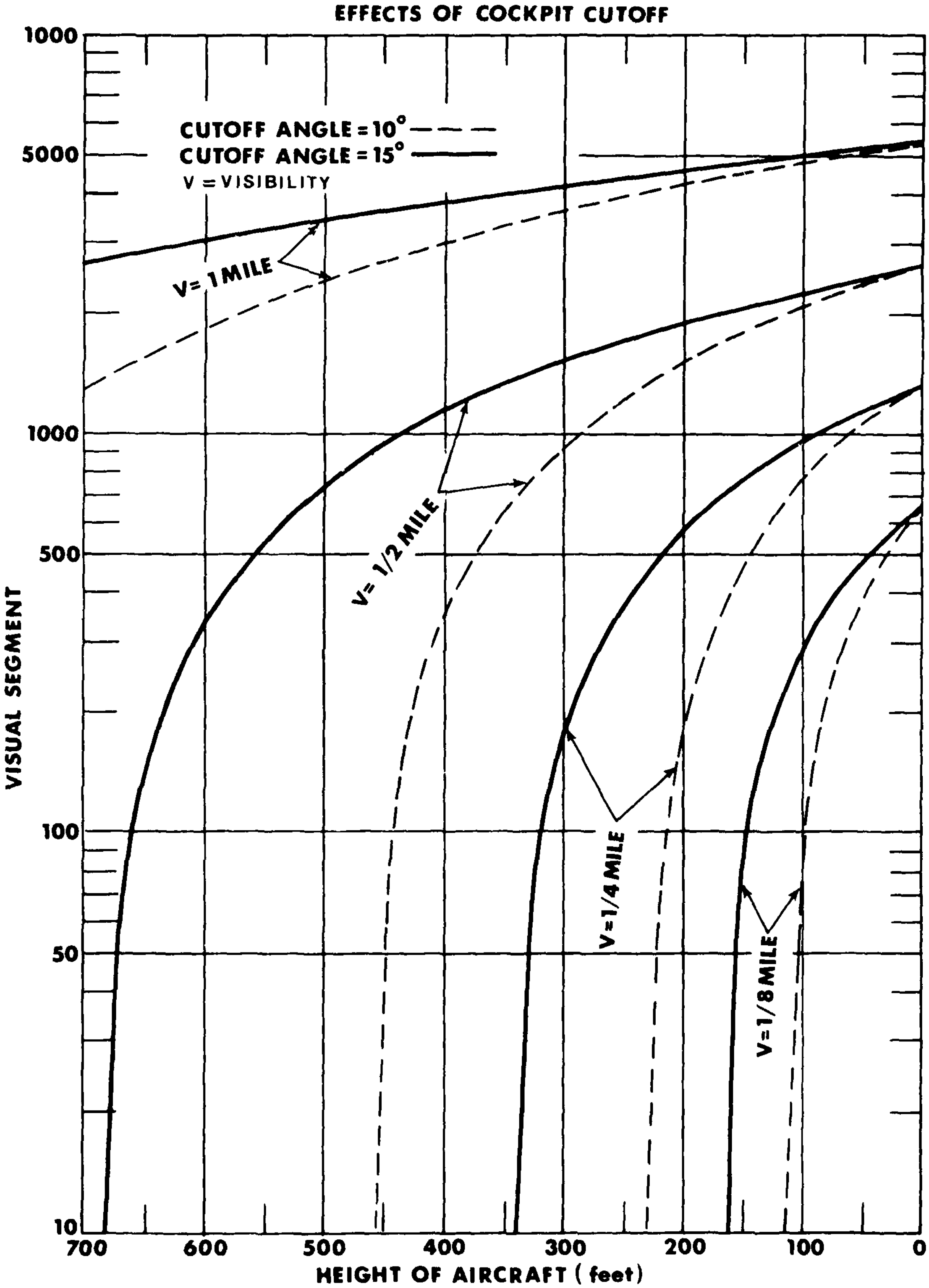

Figure 4. Effects of Cockpit Cutoff on Visual Segments

ventionally, the flare is initiated near the threshold, approximately 50 feet altitude, and the aircraft is landed in the area of 2500 feet from threshold. The data from the instrument profiles contained in the Litchford and AFFDL reports show that there was a tendency for the pilots to duck-under the glide slope for the Category I approaches in order to conserve runway real estate, or in order to try to duplicate a VFR profile. Such was not the case for approaches from Category II minimums as there was insufficient time/distance/altitude information to accomplish the duck-under maneuver.

As shown in Figure 5, the cross-over point for the two types of approaches occurs at about 150 feet altitude. Prior to the cross-over point, the instrument approach demands that the aircraft be lower in altitude in comparison to where it would be at the same distance from threshold if the approach were being flown visually. After the cross-over point has been passed, the aircraft is higher when being flown on instruments than when being flown visually.

When making a Category II or Category IIIa approach, it will appear to the pilot that he is "high" when initial visual contact is established in relation to where he would normally be in making a visual approach. As far more approaches are made visually, there is some reason to think that the pilots would be inclined to steepen the approach descent angle in order to bring the aircraft to its "normal position in space" in order to establish a visual pattern that is more in keeping with what they normally experience. This tendency, as indicated earlier, may be supported by the "need" to bring the aimpoint into view if it cannot be seen due to obscuration.

A program was flown by the AFFDL to examine the issue of how similar the VFR profile should be to the IFR profile when making approaches under simulated Cat I, II and III conditions (Ref. 14). The envelope as bounded by the VFR and IFR profiles was systematically examined by a T-38 and a T-39 test aircraft equipped with an Advanced Instrument Landing System. It was determined that in both cases, the preferred profiles were closer to the VFR profile than the IFR profile. Furthermore, the preferred profiles were flown with more precision than the IFR profiles.

The geometry of the approach then is a factor that must be considered in assessing the performance of the pilot in making low visibility approaches. The visual approach has a geometry that is different than the IFR approach. A study of the problem shows that the geometry of the instrument approach is not optimum. This is not surprising when one recognizes that the geometry of the ILS was established in the middle 30s as an "approach" aid only for aircraft of another era.

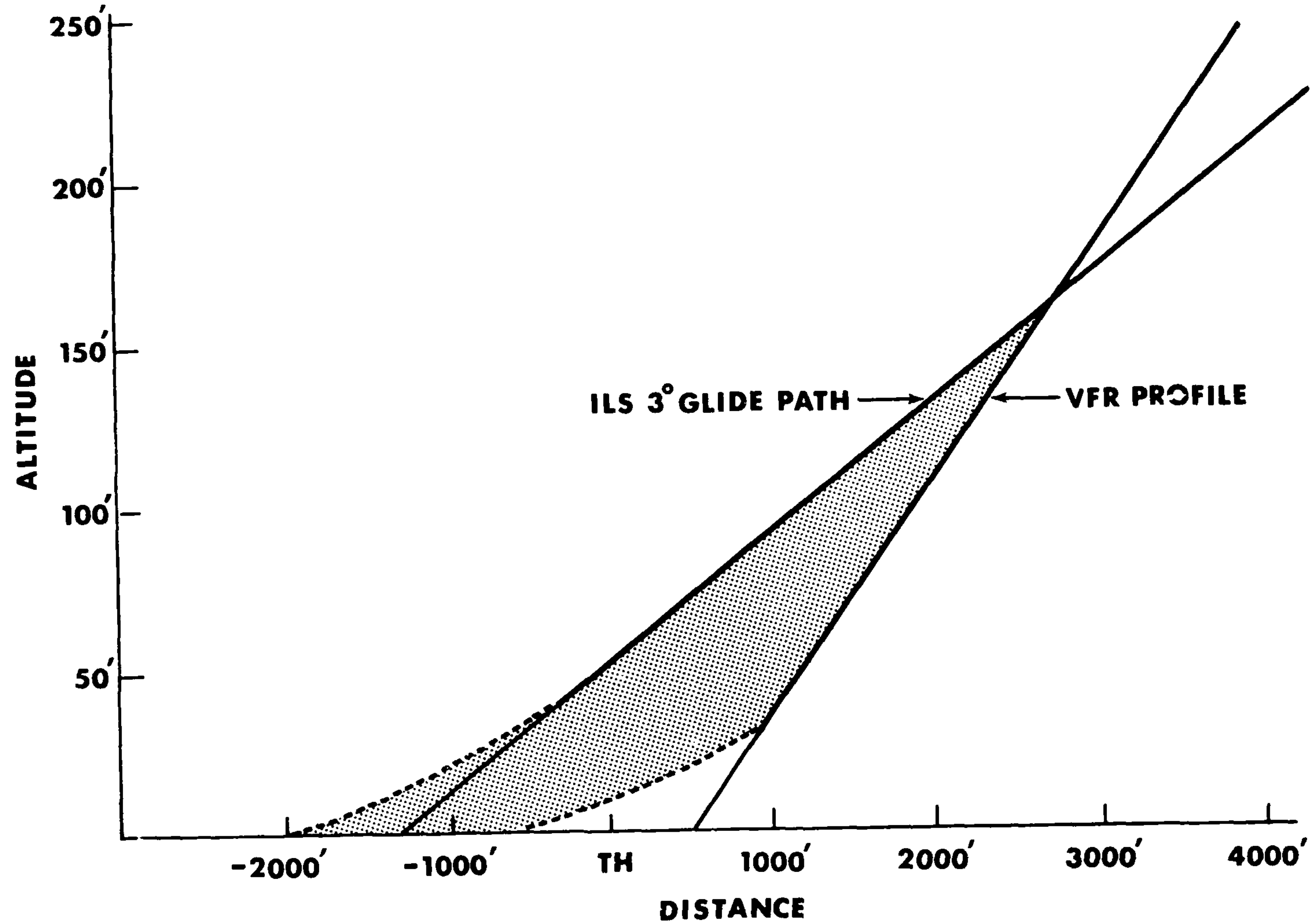

Figure 5. VFR-IFR Profile Comparison

SECTION IV

CREW CONSIDERATIONS IN SEE-TO-LAND

The methods and precision with which the aircraft is placed in a position from which see-to-land becomes possible has direct bearing upon the see-to-land concept. The problem of getting to a decision height/point, making the decision to land or abort the approach, and completing the landing is affected by crew composition, crew duties, and workload.

A. Single Pilot Aircraft

Extremely low visibilities present severe problems for the pilot of a single place aircraft. So much so that the USAF widely practices a concept of operating only into what is considered a clear cut see-to-land situation. While no firm statistics are available, this seems to generally fall into a 300 foot ceiling and one mile visibility or better.

In the process of looking at the transition from instrument flight to see-to-land conditions, let us assume that the single pilot aircraft has been positioned for the approach and is progressing satisfactorily down the approach. The pilot may be flying the aircraft manually using localizer and glide slope data as well as computed pitch and bank steering. Or he may be using the automatic pilot and monitoring the response of the automatics. At any rate, he is exercising complete control authority of the approach under instrument conditions.

At some point the pilot must start looking outside the aircraft for visual cues. He will now have to divide his attention between his instruments and the outside world. This will require a constant focusing and refocusing of vision. Studies by the Royal Air Force Institute of Aviation Medicine have shown that a visual time lag is involved in shifting from outside references to the instruments and back again under reduced visibility. The study took into account movement of the eye muscle, the movement of the eye itself, foveal perception accomodation, recognition of instrument readings, and relaxation of accomodation. The average time lapse for this process took 2.39 seconds (Ref. 15).

Taking the physical visual time lag into consideration along with the required 3 to 4 seconds previously indicated to mentally assimilate and make use of visual cues, begins to establish the time/altitude constraints in single piloted aircraft. Of course, the probability that the pilot is looking at the right area at the exact time the visual cues become available must also be considered.

The ALPA All Weather Flying Committee advanced and confirmed a theory concerning visual acuity that also has bearing on the matter. Their theory states that under low visibility conditions, a pilot who is head-up looking for visual cues will, as the cues suddenly appear, be able to see them, while the pilot who suddenly looks up from his instrument panel will not be able to see them. Their explanation for this involved scientific fact and was based on observations made in the Fog Chamber at Berkley, California (Ref. 15).

> "A person's central or foveal vision contains some 6 million cones that relate detail and clarity as well as color vision to the brain. As these cones spread out over the retina of the eye, they become increasingly sparse and are replaced by some 125 million rods, which transmit black and white images only and control peripheral vision. Any colored lights that appear solely in a person's peripheral vision will tend, therefore, to lose their color effectiveness, and low visibilities will further tend to obscure them. The pilot who is "head-up" has become almost completely adjusted to long range vision and, as the fragmentary cues of the approach lights pass underneath him, he sees them in the first portion as well as the extremities of his peripheral vision. At the 100 foot point he is less than 1200 feet from the threshold, he will see what he is looking for, the green threshold lights, and he will see them in his foveal vision. On the other hand, when the pilot who has been observing panel instruments suddenly looks up, he is acutely aware that he is very close to the ground, traveling at a high speed, still descending yet not knowing his exact rate of closure with the ground and, being a normal human being who doesn't want to make an inadvertent contact with the surface, he will grasp at the first and closest visual cues he sees to assure himself that he is still safe. These will be the approach lights that are beginning to disappear under the nose of the aircraft because they are not only the nearest cues, but they are also the brightest. His foveal vision is now directed toward them, while the green threshold lights are appearing in his peripheral vision and he doesn't see them. Taking into consideration the eye accomodation of going from short range focus to long range focus, of eye movement, and of positive identification of the threshold, we found that the time involved was close to 3 seconds. Switching duties in the Fog Chamber cockpit numerous times confirmed this fact, even though the "head down" man was somewhat mentally conditioned after several runs. And furthermore, we were well rested pilots subjected to no undue tension or strain."

As in other crew configurations, pilot workload, stress fatigue, etc., must be considered as contributing to the time required for transition. It should be noted that these items are much more likely to be present and in greater magnitude in single pilot aircraft.

B. Multi-Pilot Aircraft

A relatively detailed discussion of two leading methods of "using" aircrews is in order here since crew procedures may either hinder or aid the see-to-land approach. Consideration of crew procedures/constraints must certainly be given in the selection of optimal control/display systems for particular mission requirements.

1. Method 1. This method is in widespread use by U.S. piloting groups (Ref. 15). Essentially, the aircraft commander exercises complete control of the approach and uses the co-pilot for monitoring and cueing purposes.

The aircraft commander either flys manually or uses automatic control and monitors the response of the automatics. The co-pilot monitors his instruments and calls out altitude as the approach progresses. Some procedures call for the co-pilot to cross check his instruments with those of the aircraft commander. At some predetermined point, the co-pilot begins searching for visual cues outside the cockpit. This requires him to split his attention and requires a constant focusing and refocusing of vision. He also retains altitude alert responsibility for the aircraft commander as they approach decision height (DH).

As the co-pilot begins to pick up visual cues he will devote more and more of his attention to identifying them. When, in his judgment, sufficient cues exist to visually land the aircraft, he so states to the aircraft commander who looks up and if he concurs with the copilot, proceeds to land the aircraft. If as the aircraft approaches DH, the copilot determines that insufficient visual cues are available for continuing the approach visually he so states. The aircraft commander then initiates a go-around.

In this method, the aircraft commander is not required to conduct his own visual search and is provided discreet cueing by the copilot. The copilot is not responsible for aircraft control. Therefore, he should be able to devote more time to visual aspects. Except for the sharing of crew tasks or unburdening aspects of two or more crew members, this method varies little from that of a single piloted aircraft. The copilot is faced with the same visual time lags, focusing problems, etc. as discussed for the single pilot.

There is an additional complicating factor, however, with the crew concept - the prerogatives and responsibilities of the pilot in command. There can be little doubt but that the pilot in command has ultimate responsibility for the success or failure of the approach and, therefore, must make the decision to land or execute a go-around. However, the method by its nature, essentially requires the copilot to initiate these decisions.

As the approach progresses toward DH, the copilot states sufficient cues for landing or insufficient cues - go-around. These are the judgments of the copilot and he initiates the decision for the pilot in command. In the case of a decision to continue to land, the copilot makes the decision on the basis of what he sees or has observed over a period of time. These cues may indeed be adequate for him to control the aircraft visually but he is not in control. At that point, the pilot in command comes head-up and attempts to instantaneously acquire the same visual patterns and make assessments of position and rate that the copilot has acquired and assessed during the development of the visual cues. A compounding aspect of this problem is that the copilot's decision must be confirmed by the pilot in command. Generally speaking, copilots are of less experience and may not have developed the same level of judgment in this particular situation. In any case, this method demands a two step decision making process; the first step by the copilot and the second by the pilot. Confirmation of the copilot's decision by the pilot in command requires time. Time during which the aircraft continues toward the ground!

The safety of the low visibility operation depends directly upon the correctness of the copilot's decision. It must be pointed out, however, that the incorrect decision to go-around, when in fact the aircraft could have been landed based on the cues available, carries no where near the risk that deciding to land carries when in fact a go-around should have been executed. For the go-around situation, the copilot, in effect, does commit the pilot in command to go-around without his having had the opportunity to fully assess the situation for himself. This is looked upon by many as an infringement upon the prerogatives of command.

2. Method 2. A second method of conducting the approach has evolved as a result of extensive low visibility flying by the pilots of Air France's Night Postale. It is not in wide spread use except possibly in Europe where it is employed by several airlines (Ref. 15).

In this method, the pilot or copilot flies the aircraft to the localizer. Once the aircraft is established on the localizer the copilot conducts the approach either automatically or manually while the pilot in command acts as monitor or approach "manager." Using this method, of course, burdens the co-pilot more since he is actually controlling the approach. The pilot in command on the other hand is unburdened and, therefore, has more time to evaluate approach progress, aircraft attitudes and stability, and other important approach parameters. If deviation or errors are noted, he has the opportunity to observe them and take the proper corrective action. The pilot in command in this manner forms a good idea of how the approach is progressing and what to expect as it continues.

At some predetermined point, the pilot in command must split his attention from the instruments and begin the search for visual cues. At this point he must take somewhat of a risk and assume that the copilot

will continue to properly conduct the approach and that the aircraft will continue a satisfactory approach. The pilot in command usually indicates that he is commencing his visual search by announcing "going head-up", and by placing his right hand on top of the copilot's left hand on the throttles.

As the aircraft approaches decision height, the pilot in command will have formulated his decision as to whether to continue the approach or not. If he desires to continue visually, he will announce "I have control" whereupon the co-pilot removes his left hand from the throttles and continues to "follow through" with his right on the yoke. The co-pilot remains head-down scanning the panel so that if a go-around is required for any reason he can initiate aircraft rotation and go-around while the pilot in command advances the throttles. It has been noted that when using this procedure there is a tendency for the pilot in command to take control of the aircraft too soon. That is, he may take control when sufficient cues are available for lateral control, but insufficient for vertical control.

If as the aircraft approaches decision height, the pilot in command has said nothing or has not assumed control, the co-pilot is expected to automatically execute a go-around. The policy is, at least on some airlines, to train the co-pilot to make the approach expecting to go-around unless they hear the pilot in command state "I have control" at or before the altitude at which the go-around is to be executed. These procedures do not infringe upon the prerogatives of command since these are predetermined decisions of the pilot in command that are to be executed by the co-pilot.

At this point no attempt will be made to assess the relative merits of the two methods of executing the approach. However, this brief analysis would not be complete if it were not noted that Method 1 is employed with crews that can change from flight to flight where Method 2 is undertaken only with set crews that have trained and flown together for some time. By reviewing these procedures, the importance and impact of crew procedures and procedure execution becomes obvious when considered in the context of extremely low visibility visual landings. It is further obvious that crew procedures require "fine honing" and must be provided for throughout crew training and maintained by constant practice.

SECTION V

ALTERNATIVES TO "CLEAR CUT" SEE-TO-LAND

The "clear cut" see-to-land concept requires the pilot in command to conduct a search for visual cues and determine their adequacy and suitability for accomplishing a visual landing prior to DH. Experience has shown that the pilot cannot depend on having the forecasted visibility at the decision height. The experience gained in the LWMI Study provided a chilling insight into the problems encountered in the heterogeneous fog, such as visual reference cues not being available, obscured, intermittent, or generally unreliable. It becomes evident that the pilot in command, under less than "clear cut" see-to-land conditions, is faced with traversing the terminal portion of the approach looking outside the cockpit to establish the proper visual references and attempting to make the correct decision about continuing the approach in a highly unstable environment without ready access to vital position and aircraft guidance information.

The hazards and difficulties as discussed here certainly have not gone unnoticed by the aviation community. Indeed, there appears to be a general agreement among the concerned parties as to what the problems are, but the approaches to their resolution are quite divergent. Briefly summarized, one faction has as a goal fully automatic control through touchdown and roll out, while another group is intent on the development of head-up displays (HUD) and other methods of providing the pilot with useful flight information while looking out the windshield. Both the Automatics and Augmented Visual Flight concepts for addressing the see-to-land problem are discussed in the following pages. For ease of understanding, Augmented Visual Flight is divided into two subsections: Conventional and Innovative Displays.

A. Augmented Visual Flight

1. Conventional. As restrictions to visibility impact upon operational capability, various attempts to augment visual cues have taken place. They have taken several forms but have been aimed primarily at augmenting the pilot's slant visual range by using devices to improve the contrast ratio between the fog and the landing area. Hence, the term "augmented see-to-land" is introduced here in the discussion of some of the more successful attempts at augmentation.

a. Approach Lighting System (ALS). The present Category II lighting system was developed over a period of several years of testing and involved several million dollars of research and development effort. The LWMI report contains an evaluation of this system which was used under conditions down to less than 200 feet RVR.

The LWMI pilots concluded that the Category II lighting system would be adequate for approaches under Category II conditions. However, as the visibility decreases below Cat II, the ALS utility decreases rapidly to the point of being entirely ineffective. Again, from the LWMI report we find:

"As the visual range decreases below 1200 feet RVR, a new problem develops where insufficient cues are available to flare the aircraft day or night. As the visibility approaches 200 RVR, the entire ALS can be considered ineffective even for lateral control. The threshold, red terminating bar and wing lights may provide cues for the head-up pilot. However, these cues at best will provide marginal lateral position information and the flare must certainly be controlled by instruments."

The FAA also considers the limits for use of the ALS to be about 1200 feet RVR. In their reply to a recommendation by NTSB concerning improved approach lights following a crash at Charleston, West Virginia in 1968 (Ref. 16), the FAA had this to say:

"The U.S. Standard Configuration A approach light system is acceptable for minima as low as 1200 feet RVR."

It should be noted that the geometry of the approach is such that very little of the approach light system (approximately 500') is visible to the pilot at a DH of 100 feet, which in turn is in diminishing view for less than three seconds! As the name implies, it is an approach light system and not a landing system. From the foregoing, it can be concluded that the approach light system as now designed has about reached its limits as a vision augmenter at Category II minimums.

b. Runway Lighting System. Touchdown zone (TDZ), centerline (CL) and high intensity runway edge lights (HIRL) have been found to extend the see-to-land capability. Tests indicate they are generally satisfactory for lateral guidance for Category II, but also lose effectiveness rapidly as the visibility decreases, becoming ineffective for landing purposes below 800 feet RVR. The centerline lighting fixtures, however, have been found effective for roll out guidance during night operations in visibilities as low as zero-zero. This finding has bearing upon Category IIIA operations where the roll out may be accomplished visually.

c. Runway Markings. Somewhat surprisingly, runway markings assume more importance during low visibility approaches and landings than might be supposed. As the LWMI project pilots put it:

"In low visibility weather, runway markings assume extreme importance and in some cases, such as day approaches, may provide better visual references than centerline or touchdown zone lighting."

While existing marking systems certainly provide assistance during low visibility approaches and landings, improvements hold more promise for assisting in visual take-off rolls and landing rollouts than for extending see-to-land. A note here, however, is in order from the LWMI study. Project pilots found the new FAA developed 3-3-2-2-1-1-1-1 pattern inferior to the 2000 feet system it is replacing. They considered the 1000 feet touchdown aim points an undesirable "forcing function". They felt that the new system degraded the concept of providing distance from threshold information by repeating the marking patterns. Several other recommendations for improvement of the systems were made which should be given serious consideration for Category III operations (Ref. 3).

d. Visual Approach Slope Indicators (VASI). Although VASI systems are normally thought of as for use during purely visual approaches, they blend very well with instrument approaches. For example, during a precision approach, the VASI acts as an extension of the glide slope and permits a smooth transition from instrument to visual flight. Since the VASI and precision glide slopes are normally aligned with each other, the transition from one glide slope reference to the other can be made without power, pitch or trim changes. The pilot merely continues with the same attitude and power to the flare point.

2. Innovative Display for Augmenting Visual Flight

Head-Up Displays (HUD). In efforts to assist the pilot in being fully informed as to the status of his aircraft and the approach progress while looking outside, a great deal of time and resources have been expended in developing head-up displays. Indeed many displays have been developed and some are in use, but it is certainly not possible to conclude that any given display is entirely adequate or even that the concept is a valid one for extension of see-to-land. Yet, the HUD is considered by many to be a "panacea" for approaches and landings under all conditions of visibility from unlimited to zero-zero.

Results of research and experiences to date are quite varied. However, one of the most exhaustive and realistic tests of the effects of a HUD on piloting tasks has been completed by the University of California in the UC-FAA Fog Chamber facility (Ref. 17). The head-up display element used was a Singer-Librascope L-193 Head-Up Display Unit. Some very specific conclusions were drawn which are applicable to these discussions and are quoted below.

> "The general concept of providing the pilot with a display of pertinent aircraft attitude information in the normal line of sight combined with the external scene may have some advantage over the conventional mode of changing from head-down to head-up at the appropriate time. This advantage does not include any improvement in the distance from the threshold when the pilot making a simulated approach may decide to land or abort. (Underlining by authors for emphasis.)

The principal advantage cited by most of the subject pilots in the dynamic studies was a greater sense of security. Pilot comments indicate that reliance on external visual cues is very great; the ability to monitor the aircraft attitude and at the same time "see" the approach light and runway light system gives the pilot confidence that his judgment concerning the aircraft attitude is correct.

The finite difference between decision points for head-up runs versus the head-down mode for all pilots under all conditions was 36 real feet in favor of the head-down mode. This gives the normal approach procedure a small lead time (.08 of a second) over an approach using the head-up display. This is in the light sources viewed through a 55% transmittance combining glass. The calculated reduction is in the order of 5% at night and 0.5% during the day. Based on 1200 feet visibility for Category II conditions, this reduction is approximately 60 feet under nighttime conditions and, because of the changes in background brightness, approximately 6 feet during the daytime. These numbers are close to the differences experienced in the day and night runs with the 1200 feet VR. This would reinforce the argument that the head-up display as projected by the Singer-Librascope L-193 neither helps nor hinders the pilot's ability to make judgment decisions when making simulated approaches under low visibility (i.e., fog) conditions."

Independent research, as well as the expert opinion of many, would indicate that the HUD may have real value in extending see-to-land minimums relative to the earlier discussion of the requirement to see the runway or aim point for reliable vertical axis control. Capt Richard Beck in his paper "1200 RVR - Cleared to Land" (Ref. 18) was one of the first to suggest this possibility.

"...although there may be adequate visual guidance for correcting lateral errors, there appears to be a need for instrument guidance in pitch to very low altitudes. This control in pitch can be implemented through a correctly engineered automatic approach coupler, a properly engineered flight director, or a head-up display. Ideally, the head-up display appears to be the best suited for Category II at this time, because to be safe, decisions have got to be made rapidly and correctly and one man must have all the essential information. Head-up display will do this by allowing the pilot to use instrument guidance in pitch with visual guidance in Azimuth as well." (Underlining by authors for emphasis.)

The Royal Aircraft Establishments "Initial investigation of head-up display at B.L.E.U." (Ref. 12) supports Capt Beck's position.

> "In the future, the head-up display will allow a pilot to fly the aircraft using instrument guidance in pitch with visual guidance in Azimuth and is, therefore, an ideal solution to overcome the safety problem of the visual phase." (Underlining by authors for emphasis.)

The results that were obtained by the AFFDL/IFC do not support the rather optimistic projections for HUD made by Capt. Beck and B.L.E.U. Approximately 35 approaches were made in weather down to 400 RVR using a modified Peripheral Command Indicator (PCI) as a "HUD" device. A schematic of the PCI is presented in Figure 6. It was located on the nose of the test T-39 aircraft approximately eight feet from the pilot's eye reference point. At this distance the pilot could, theoretically, focus his eyes at infinity and still assimilate the information from the PCI. The display was found deficient in that attitude information was not presented. However, the IFC deemed it adequate as a tool for studying some of the pilot factors aspects of using a HUD in low visibility (Ref. 19). The summary of results is presented below:

a. While using the HUD for guidance, visual cue acquisition time was increased over visual cue acquisition without a HUD. (This agrees with the results of the work done in the Fog Chamber.)

b. Use of the HUD degrades early perception of visual cues as the attention of the pilot is on the HUD and not on the external scene. (Five dynamic cues were displayed on the PCI.)

c. The pilots did not focus on infinity and simultaneously acquire information from both the HUD and the external scene. They "switched" from one to the other.

d. Confusion arose in the low visibility approaches - less than Cat II - when there was sufficient visual information for lateral control but not vertical control. The pilots were unable to use the visual world for lateral control and the HUD for vertical. The tendency was to stay on the HUD for both lateral and vertical guidance.

e. As altitude decreased, scan pattern decreased to allow greater concentration on the PCI. Consequently, many of the runway cues were missed entirely.

The use of the HUD in less than Cat II requires that the old axiom of never mixing contact and instrument flight be violated when sufficient cues are available for lateral control, but not vertical. However, all things considered, it does not appear at this time that the HUD is a viable device for extending see-to-land minimums below clear cut see-to-land.

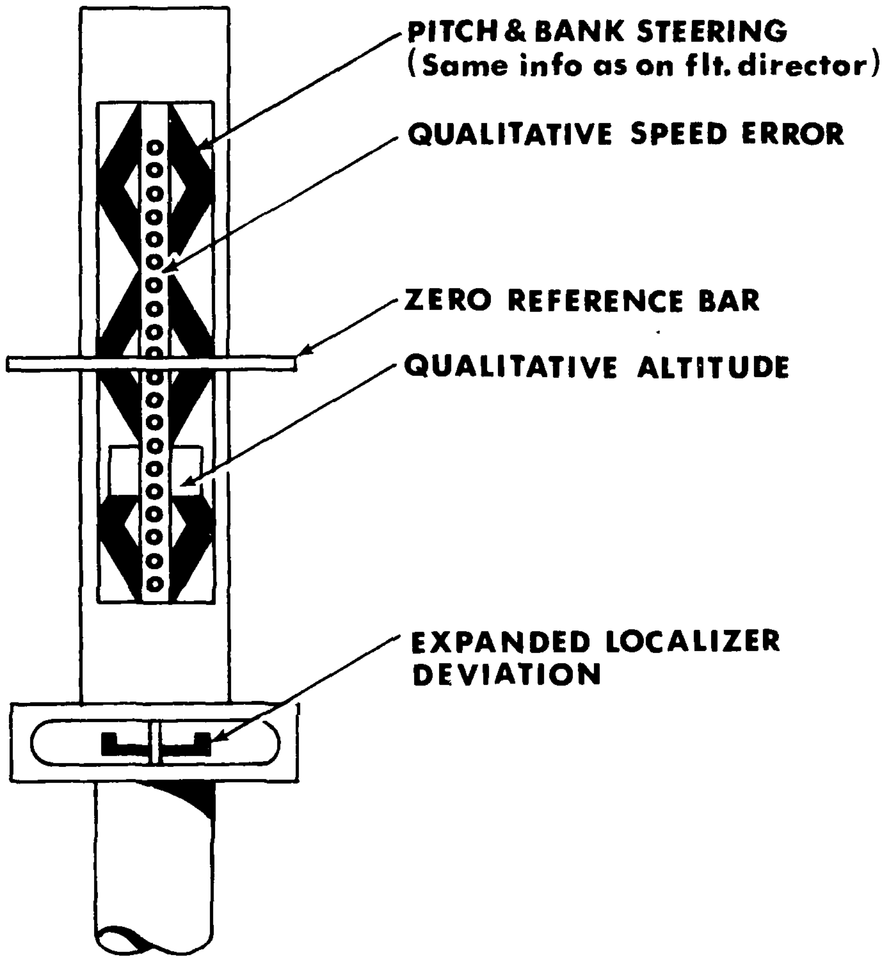

Figure 6. Peripheral Command Indicator

Additional research has to be done. Extracting information from the obscured external scene - first with lateral information and finally adding vertical control information is a serious problem. This problem, coupled with delay tendencies in transitioning from HUD guidance to external world guidance, while narrowing the HUD scan pattern, must be resolved prior to advancing the notion that HUD buys lower minima.

At this point there are very few advocates of HUD that believe HUD's will be adequate for "zero-zero" operations. Indeed, in a truly "zero-zero" situation the requirement for a HUD becomes a moot point. That is, since nothing is to be seen through the wind screen, nothing is accomplished by having a HUD installed, other than a change in pilot's head position. It would also seem unlikely that "zero-zero" landing HUD displays for either automatic monitoring or manual control can be readily achieved since, to date, technology has not been developed and demonstrated for a head-down zero/zero landing capability. It must also be noted that to date, most HUD development efforts have led to attempts to duplicate head-down information on the head-up display. The limited space on head-up displays dictates that it would be foolish to submit to the luxury of putting more than the most essential information on a HUD.

Even though head-up displays have been discussed for years and a variety of them have been built and tested, they are not in widespread use. Possibly the reason for this is that the <u>role of the HUD has never been clearly established in actual low visibility conditions</u>. Since the role is hazy, the information content and format is ill defined and a "shot gun" approach has frequently been used.

There are a multitude of questions to be answered about HUD before its role, information format and content can be established and the device can be given proper consideration as an integral part of the overall system.

B. "No See-To-Land" Systems

It should now be obvious that the less than "clear-cut" see-to-land situation is fraught with the hazards of illusions, lack of information, and many others. All of the attempts at visually augmenting the see-to-land situation still results ultimately in <u>the pilot having to make the decision to land or go-around on the basis of what he sees</u>. The potential reduced minima credits that might accrue with the augmented concepts only places the pilot deeper into the hazards of the quasi see-to-land region with less time and altitude remaining before impacting the ground. It becomes obvious that if the mission or other factors require a capability to operate below "clear-cut" see-to-land minimums, serious considerations must be given to the current efforts being made toward achieving that goal in terms of safety, economics, system reliability and maintenance and piloting considerations.

If requirements dictate a "no see-to-land" capability, consideration must be given to current efforts directed toward achieving that goal.

Basically two approaches are being taken with the difference in approaches being concerned with the assigned role of the pilots during the final phase of the landing approach. One concept is that of a completely automatic landing. The other concept is that which includes the pilot as an active control element and an adjunct to the automatic system. Both concepts make use of an autopilot as the primary means of control to touchdown. The concepts differ in the matter of fault survival and the pilots role in monitoring and fault correction.

1. Automatic Landing System. The fully automatic landing system includes a redundant capability which allows automatic elimination of faulty channels. The success or failure of the approach and touchdown rests with the system, while the role of the pilot is that of systems monitor, taking control only in the event of some unforeseen emergency. The all-automatic landing system is technologically feasible and could conceivably be operated without special control and display systems.

Drawbacks or shortcomings of this system lie in the areas of system costs, maintenance and reliability and possibly even more important - pilot, passenger, and management acceptance. Acceptance will be difficult to achieve in a truly automatic system because (1) the flexibility and judgment capabilities of the pilot are essentially negated by the lack of adequate displays that should provide the same finite interpretable information that is provided to the autopilot; and (2) because of the lack of proper access to the automatic controls in the event it was deemed necessary. These considerations cast doubt that this concept will ever be appealing or accepted by the pilot populace or the informed passengers.

With a fully automatic landing system, the placement of responsibility in the event of a catastrophic automatic "arrival" could no longer be attributed to "pilot error" since equipment suppliers and management decisions become involved. The purely automatic landing solution with present pilot responsibilities would give the pilot ultimate responsibility for approach success without providing the proper access to both the control and the displays required to allow the pilot to meet his responsibilities as aircraft commander.

In addition to the question of acceptance and responsibilities raised by purely automatic landings, there is the issue of adverse pilot workload being imposed, paradoxically, just when relief is required the most. Two situations are particularly acute. First, when the see-to-land option is exercised, as in Cat II, present procedure dictates that the automatics be disengaged and the pilot assume full manual control. However, if the pilot and automatics were actively integrated throughout approach and landing, the pilot could continue to impose his inputs into the system while retaining the assistance of the autopilot during the most demanding part of the landing maneuver. In the second case, when flying an automatic approach and landing as in Cat III, the fully automatic system should not be disengaged in the event of a partial failure of the system. More appropriately, the pilot should retain the assistance of that part of the auto-

matic system that is working and fly the failed axis manually in a "split axis" configuration. From these two situations it can be seen that the assistance available to the pilot from the automatics is significant and can be critical. The total system, therefore, should be designed so that it is not an all or nothing automatic approach and landing system.

The FAA sponsored Pilot Factors Program accomplished by the AFFDL/IFC during the '60's made significant findings relative to the use of present day displays for manual instrument landings or monitoring of automatics (Ref. 20):

> "The flight director with standard settings and with pitot-sensed instruments did not provide sufficient information in either quality or kind to cope with the problems of flying on instruments inside the middle marker. As expected, the utility of the standard instrument panel began to deteriorate at 200 feet - the middle marker - and became completely unacceptable at 100 feet."

It should be emphasized that the panel used for the investigation was quite similar to those in use today for Cat. II approaches and not significantly different from those being used and advocated for Cat IIIa.

It is illogical to assume that displays that are inadequate for precise control of the aircraft by the pilot are adequate for monitoring of an automatic system. Monitoring connotates that excursions from the desired will be detected and corrected. But it seems more logical to assume that if the pilot is unable to conduct the approach on instruments then neither will he be able to use the same displays to properly monitor the automatics. It bears repeating that displays that are not adequate for control are probably not adequate for monitoring. This is further emphasized by Capt. DeCelles of ALPA (Ref. 21):

> "We believe that airline pilots - at least in the United States - will firmly reject the monitor - only role precisely because a pilot cannot adequately monitor another pilot, whether man or machine, unless he is provided data adequate to permit him to match the capability of the pilot being monitored"....."If the display does not provide this information in a manner suitable for manual performance, in our opinion it is not adequate for the monitoring function."

Capt. St. John McCloskey of Irish Airlines had an even firmer opinion on the matter (Ref. 8).

> "What does the pilot need for the automatic blind landing? He needs a method of knowing exactly what

the automatics are doing and are about to do throughout the approach, landing and roll-out. As I approach an airfield for a blind landing, the fact that the system has a history of one million safe landings is no good to me. I want to know what is happening now during this approach. If I do not know what is happening I may as well go sit with the first class passengers - it is safer there. I am not prepared to carry on unless I am responsible, and if I am responsible, I must know exactly what is going on. I would like all concerned to be aware that there will be no surrender on this Doctrine of Overall Responsibility. We shall move not one inch!"

2. Pilot-in-the-loop for "No See-to-land". The alternative conceptual solution to the "zero-zero" landing problem lies in a "marriage" of automatics and the human pilot. The Pilot Factors Program philosophy (Ref. 20) sought to combine the best features of automatics - precision, unburdening, etc. with the human pilot qualities of judgment, flexibility and decision making. This program established that the pilot could work in harmony with an automatic system through touchdown and roll out when provided full time access to control through a specially tailored force wheel steering system. It was shown that, contrary to the belief of many, the pilot did not detract from the precision provided by the automatics.

Certainly the automatics must and should be allowed to conduct the approach as far as possible. But effective monitoring for fault correction involves the recognition of the need to do so, the taking over of control (or assertion of pilot will) in the required axis, recovery of the desired path/attitude and continuation of the approach or initiation of a go-around. Assumption of control is very difficult low to the ground unless the pilot has been actively involved as advocated by the Pilot Factors philosophy using force wheel steering. Assuming this philosophy to be correct, the problem of continuing the approach or going around is mainly a display problem as things now stand.

The technology has been generated and demonstrated to achieve fully automatic landings. The systems derived from this technology minimize the requirement for the pilot to have to take over manually in a given axis or even to perform a manual landing or go around because of the unlikelihood of failure. Technology for pilot access to control has been verified. As was discussed earlier, in order for the pilot to effectively function as a monitor, he must have the same displays as required to perform the task being monitored and, therefore, must be provided with the required displays before proceeding beyond the "clear-cut" see-to-land situation, either automatically or as a pilot-in-the-loop.

The full time pilot-in-the-loop option appears a desirable one for consideration because it retains the precision and unburdening aspects of the automatics. It allows the human pilot to function as "the reliable

element" taking advantage of his unique capabilities as a decision maker. Pilot, passenger and manager acceptance may be relatively easy to gain. Economic and maintenance aspects of such a system appear more favorable. Some variations of pilot-in-the-loop systems are presently available.

The pilot-in-the-loop technology was generated by the Pilot Factors Program in the 1962-1964 time period (Ref. 20). Component pieces of the technology, notably the integrated flight director/autopilot have been incorporated in all major commercial and military aircraft developed since that time. However, the system concept of blended manual/automatic control was prostituted in application. The force wheel feature was incorporated as a "special mode" in conjunction with a control augmented system (CAS) rather than as a full time feature allowing pilot inputs anytime the automatics were engaged, as advanced in the Pilot Factors Program work.

The pilot-in-the-loop concept also needs further work. Just as with the fully automatic system, pilot displays have not been adequately developed and proven to allow pilot monitoring/performance to touchdown in conjunction with the automatics. Training and maintenance of pilot proficiency in skills that are required during only a small percentage of his total approaches may be difficult to accomplish. In short, as with the fully automatic concept, the pilot-in-the-loop concept requires further verification, refinement and additional display technology.

SECTION VI

SUMMARY AND CONCLUSIONS

The thrust of the paper has been directed to two points. First, the decision to go-around or continue the approach below Category I minima is made in a potentially unstable environment that must be considered hostile by any pilot. Secondly, present crew procedures do not add significantly to the safety of the operation.

Taking all the factors into account leads to the conclusion that the see-to-land concept is critically limited. Different types of obscurations may be encountered below 200 feet altitude. Certainly, the visibility conditions can vary widely from one approach to another, while significantly varying within an approach. The derivation of visual guidance information from the external world evolves gradually with first lateral and then vertical guidance becoming available. This increases the difficulty of transitioning from instruments to visual (including the HUD) in a highly time dependent situation. The geometry of the instrument approach is not optimized. Lighting and runway markings are useful, but do not by themselves provide the margin of safety required. The pilot does not have access to reliable information on visibility conditions along the approach. Furthermore, the pilot is given no clear guidance of what he must see in order to continue the approach below the decision height. The pilot must carry the full responsibility for making a decision for each and every approach under a set of particular circumstances that he may never have seen in a career of flying and might never encounter again.

Data from the AFFDL/IFC programs, Fog Chamber experiments, and B.L.E.U. pretty well agree that the visual segment limits for reliable see-to-land is around 600-800 feet for marginal control of the vertical situation and also, the aim point must be in view for real reliability. It is the conclusion of this paper that the present Category II minimum of 1200 feet is, with qualification, just at or slightly below the lower limits of reliable see-to-land, depending upon the particular circumstances. The qualification is based upon the requirement to make the decision process easier than it is now for the pilot to arrive at the correct determination of continuing or going around. The process of making the decision must be structured and crew procedure must be refined if the job is to be made easier.

A. DH as a Function of Pilot Considerations

It seems from the preceding discussions that it might be possible to develop procedures and regulatory materials that would simplify and assist the pilot in making the critical decision at DH which is nearly always made under conditions of stress and high workload. It would seem possible and desirable to make the decision process as easy and simple as possible in

order to give absolute assurance to the pilot that he has adequate visual cues to control the aircraft and that he will continue to have them to touchdown. By using combinations and modifications to existing procedures, the scenario might be something like this:

> As the approach progresses to a predetermined point, the search for visual cues is initiated. As the cues become available they are used for position determination, establishments of rates, etc. As a "certain" key point is approached, a decision is made as to whether or not the required visual segment is available. This decision is made by a yes or no answer to the question "Can I (the pilot) see the required distance* along the approach path?"

Capt. DeCelles of ALPA has long advocated that the runway threshold be in sight before continuing beyond DH. FAA has no problem with this requirement (Ref. 22). Capt DeCelles has also stated "that the target area must be in view for a sufficient period of time to permit assessment of its position and apparent motion relative to the threshold and edge lines of the runway and to the aiming section of the windshield" (Ref. 23). This represents a more demanding requirement than just seeing the threshold or projected aimpoint.

In considering solutions to meeting the stated requirements it is proposed that a DH/RVR relationship be established that in effect guarantees the required SVR at DH and becomes an either/or situation. In effect the concept provides for the pilot to incrementally assess the SVR from the cockpit during the approach and landing. At DH the pilot must either have the threshold in sight ("Guaranteeing" at least momentarily the required visual segment for continuing) or a go-around must be initiated...No counting of light bars - No pressing while hoping the visibility improves - Just a simple "I see the threshold - continue" or "I don't see the threshold - go-around."

The discussion to this point is concerned with established acquisition of the required SVR before proceeding beyond DH. Since our goal was to assure adequate guidance for visual control to touchdown, a second discreet observation of SVR is in order. This second observation may be defined by using 1200 feet SVR as the desired condition and by applying normal approach geometry, we derive an altitude at which a go-around must be initiated unless the GPIP or aimpoint is in sight. In this case that altitude would be approximately 70 feet. Again a single "yes, I see the aimpoint - land" would suffice. Of course, the aimpoint or GPIP must be clearly defined and readily identifiable. A high intensity VASI-type device flush mounted on the runway would seem to be an attractive possibility. Not only would it identify the GPIP, but it would also provide visual vertical guidance.

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*Required distance being the leading edge of the required visual segment (to be determined by studies underway and expert opinion).

It should be noted that this concept will require "adjusting" the DH so that it occurs not later than the minimum required SVR. In other words, if the required SVR is 1200 feet, the adjusted DH altitude must occur not lower than the point identified on the published glide slope which will occur precisely 1200 feet prior to GPIP. Using the previously discussed probability of 80-90% and SVR/RVR ratio of 0.65 to 0.85, the RVR in this case would be approximately 1600 feet*.

In summary, two key points are established: first a DH at which the pilot is assured of a sufficient visual segment to continue the approach through observation of the threshold and a second point where the pilot's visual segment includes the aimpoint (VASI's), lending assurance that a safe visual landing can be accomplished.

It will be noted that these decision points are based upon piloting requirements and not, as DH's are now derived, upon the quality of guidance and the airport facilities. Due consideration must be given both. In some cases obstacles, facilities, etc., will dictate higher DH/RVR than that required for a visual landing. As the visibility lowers the reverse may be true - piloting requirements may dictate a higher DH than would otherwise be required.

B. Crew Procedures

As was implied earlier, crew procedures must be considered when conducting approaches into low visibility conditions. Procedures used within the U.S. were not, by and large, developed with low visibility requirements in mind but rather those of skill levels, pilot in command prerogatives, etc. The European or Air France Night Postale procedures were developed and refined specifically to enhance low visibility approach success and appears to have done so. Assessment of these procedures resulted in their adaption in slightly modified form for use in the LWMI study. As a result of this study further refinement was recommended by the pilots of the LWMI study. Although somewhat lengthy, their recommendations are reproduced here in their entirety because of their basis and value.

> "A solution to the crew procedures question would be to assign one pilot the responsibility for visual decisions and the other for instrument flight. As visual references become available, the visual pilot could use verbal cues to alert the instrument pilot about their identity, magnitude and utility. In this manner instrument flight can be maintained to touchdown, confidence is instilled in the instrument pilot as he receives information relating the visual environment. Also important, control integrity would not be sacrificed if a missed approach is necessary at or below decision height. To complement this crew concept, the visual pilot could assist as the visual environment allows, first in the lateral axis, then in the longitudinal axis and then take complete control at touchdown for the rollout and taxi."

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* Interestingly, this happens to coincide with the minimum RVR felt necessary by the LWMI project pilots for visual aircraft control.

"The crew's roles should surely include the total integration of their efforts along with the unburdening aspects of an automatic (force wheel steering type) flight control sytem with a flare and landing capability. Theoretically it would seem plausible, if not absolutely essential, to assume that both pilots should have at their disposal the flight control/display systems to singularly or dually accomplish flight to touchdown solely with instrumentation. The basic act of aircraft control seems somewhat trivial, but the prerogative of command should ideally rest with the aircraft commander. The aircraft commander should be the decision maker, while the other pilot is responsible for instrument flight. If a fault warning system is not included in the system's design, consideration should be given towards a third pilot performing this function."

"The aircraft commander would normally be the overseer for the entire flight, directing the efforts of the crew, assigning duties and making critical decisions. In the case of low visibility landing, the aircraft commander would assume a visual posture at some predetermined altitude, evaluate the visual environment and make the land or go-around decision. Since he would have access to the visual environment, he could assist with path control when able, or monitor the co-pilot during the entire approach and touchdown."

"The instrument pilot would execute physical authority over the automatic flight control system (AFCS), assisting in the tracking function by inserting control inputs as necessary. His primary function would be the overt management of the AFCS through control inputs and selection of the proper automatic modes during the approach."

"Until passing the final approach fix, it is anticipated the aircraft commander would direct, at his discretion, the accomplishment of communications and aircraft configuration procedures. However, once the final approach fix is passed, the aircraft should be in its landing configuration (to prevent instability problems on short final), and the visual pilot should assume full responsibility for radio communications. The reason for this assignment is two-fold. The visual pilot, since he is the overseer for the approach, would be alert to the total situation, both inside and outside the aircraft. This also permits the instrument pilot to concentrate on systems performance, assessing the need for control inputs, and exercising proper control over the automatic system without distraction."

"Since the visual pilot is alert to the geometry of the approach profile and the status of the ground environment, he should naturally assume the role of decision maker. In

his role of decision maker, he would be responsible for the land or go-around decision and also for conveying information regarding the approach to the pilot flying the instrument approach. This concept was found extremely important during the LWMI and may have merit during routine low visibility landings. The following verbal procedures were used during the LWMI. The first call was "CUE" which meant that portions of the runway environment were coming into view, but insufficient visual information was available to control the aircraft. The second call was "LATERAL", meaning that the visual cues were sufficient to laterally align the aircraft with the runway centerline; however, insufficient visual information was available to flare the aircraft. Also, at the Lateral command, the visual pilot exercised his prerogative and assisted with lateral axis control. It is extremely important to stress at this point that there was no transfer of aircraft control and the instrument pilot was still tasked to maintain instrument flight. When the visual pilot had sufficient references to visually control the aircraft he called, "VISUAL". At this time he could at his discretion, aid with aircraft control with inputs into both the lateral and longitudinal axes. There was still no transfer of control. If the visual pilot wished to take complete control, he would state, "I have the aircraft", and assume complete control while the instrument pilot relinquished complete authority. It was anticipated that this command would be executed by the visual pilot only after the aircraft was safely on the runway, at which time he would assume active control for the rollout. The instrument pilot would then be responsible for configuring the aircraft for the rollout."

"Another important decision that must be made is whether or not to execute a go-around. This decision should be made by the visual pilot and executed by the instrument pilot on the verbal command, "GO-AROUND". The roles of the pilots should be exact and specific as the go-around is commanded. The instrument pilot should execute the maneuver since he has physical control of the aircraft. The visual pilot would be evaluating the weather environment on final approach and hence direct the appropriate command. When a go-around is made, the visual pilot reconfigures the aircraft, leaving the other pilot free to concentrate on the go-around maneuver. Again, the main principle is to unburden the aircraft commander, who would normally be the decision maker and visual pilot, while eliminating any transfer of control during the final approach, flare and landing."

C. Final Conclusion

The considerable research required to develop this paper coupled with a combined total experience of over 30 years in working with the low visibility landing problem have lead the authors to the conclusion that there are only two real choices to be made in terms of landing capability.

1) Clear-cut assured see-to-land limits considering pilot constraints, and

2) a combination of automatics and pilot control/ display to allow a fully closed on instruments loop through touchdown.

The techniques and devices, i.e., HUD, Fail Passive Autopilots, which are being proposed for extending the approach into the quasi see-to-land region do not in any way change the environmental situation at the runway. The "quasi" operation still requires the pilot to make a decision based upon what he can see while much closer to impending touchdown. This almost guarantees that mistakes in judgment that are made from time to time will have more serious consequences. Therefore, these techniques and devices should be used to improve the safety and reliability of "clear-cut" see-to-land rather than attempting to lower the present see-to-land minima of 1200 RVR.

If the hypothesis can be accepted that rather than Category I, Category II and III conditions, we really have "assured, clear-cut" see-to-land or "no see-to-land," the "required capability" decision becomes an easier one. It says that for a given mission the operator may not want to pay the price to go all the way. If the operator is unwilling to pay, then he must be satisfied with a reasonable minima. The efforts should be spent on improving the safety and reliability of "clear-cut" see-to-land and the go-around that may occasionally be required if the crew cannot see-to-land from decision height. On the other hand, if the mission or economics dictate that the crew press lower than "clear-cut" see-to-land, then the operator would have to pay the price required to go all the way to touchdown with an integration of adequate instrument displays necessary for effective pilot interaction with the automatic landing system.

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